U.S. PATENT APPLICATION

FOR

IMPROVED UNDERLAYER FOR HIGH AMPLITUDE SPIN VALVE SENSORS

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IMPROVED UNDERLAYER FOR HIGH AMPLITUDE SPIN VALVE SENSORS

FIELD OF THE INVENTION

5   The present invention relates to magnetoresistive read sensors for reading signals

recorded in a magnetic medium, and more particularly, this invention relates to tailoring an

underlayer of a spin valve magnetoresistive read sensor for improving operating characteristics.

BACKGROUND OF THE INVENTION

Computer systems generally utilize auxiliary memory storage devices having media

10   on which data can be written and from which data can be read for later use. A direct access

storage device (disk drive) incorporating rotating magnetic disks is commonly used for

storing data in magnetic form on the disk surfaces. Data is recorded on concentric, radially

spaced tracks on the disk surfaces. Magnetic heads including read sensors are then used to

read data from the tracks on the disk surfaces.

15   In high capacity disk drives, magnetoresistive read sensors, commonly referred to as

MR heads, are the prevailing read sensors because of their capability to read data from a

surface of a disk at greater linear densities than thin film inductive heads. An MR sensor

detects a magnetic field through the change in the resistance of its MR sensing layer (also

referred to as an "MR element") as a function of the strength and direction of the magnetic

20   flux being sensed by the MR layer.

The conventional MR sensor operates on the basis of the anisotropic magnetoresistive

(AMR) effect in which an MR element resistance varies as the square of the cosine of the

angle between the magnetization of the MR element and the direction of sense current

flowing through the MR element. Recorded data can be read from a magnetic medium

because the external magnetic field from the recorded magnetic medium (the signal field) causes a change in the direction of magnetization in the MR element, which in turn causes a change in resistance in the MR element and a corresponding change in the sensed current or voltage.

5   Another type of MR sensor is the giant magnetoresistance (GMR) sensor manifesting the GMR effect. In GMR sensors, the resistance of the MR sensing layer varies as a function of the spin-dependent transmission of the conduction electrons between magnetic layers separated by a non-magnetic layer (spacer) and the accompanying spin-dependent scattering which takes place at the interface of the magnetic and non-magnetic layers and within the 10   magnetic layers.

          GMR sensors using only two layers of ferromagnetic material separated by a layer of non-magnetic electrically conductive material are generally referred to as spin valve (SV) sensors manifesting the GMR effect (SV effect). In a spin valve sensor, one of the ferromagnetic layers, referred to as the pinned layer, has its magnetization typically pinned by 15   exchange coupling with an antiferromagnetic (e.g., NiO, FeMn, PtMn) layer. The magnetization of the other ferromagnetic layer, referred to as the free layer, however, is not fixed and is free to rotate in response to the field from the recorded magnetic medium (the signal field). In spin valve sensors, the spin valve effect varies as the cosine of the angle between the magnetization of the pinned layer and the magnetization of the free layer.

20   Recorded data can be read from a magnetic medium because the external magnetic field from the recorded magnetic medium causes a change in the direction of magnetization in the free layer, which in turn causes a change in resistance of the spin valve sensor and a corresponding change in the sensed current or voltage. It should be noted that the AMR effect is also present in the spin valve sensor free layer.

FIG. 1 shows a typical spin valve sensor **100** (not drawn to scale) comprising end

regions **104** and **106** separated by a central region **102**. The central region **102** has defined

edges and the end regions are contiguous with and abut the edges of the central region. A free

layer (free ferromagnetic layer) **110** is separated from a pinned layer (pinned ferromagnetic

5   layer) **120** by a non-magnetic, electrically-conducting spacer **115**. The magnetization of the

pinned layer **120** is fixed through exchange coupling with an antiferromagnetic (AFM) **125**.

An underlayer **126** is positioned below the AFM layer **125**.

The underlayer **126**, or seed layer, is any layer deposited to modify the

crystallographic texture or grain size of the subsequent layers, and may not be needed

10   depending on the substrate. A variety of oxide and/or metal materials have been employed to

·construct underlayer **126** for improving the properties of spin valve sensors. Often, the

underlayer **126** may be formed of tantalum (Ta), zirconium (Zr), hafnium (Hf), or yttrium (Y).

Ideally, such layer comprises NiFeCr in order to further improve operational characteristics.

In particular, NiFeCr underlayer has been very successful in improving operational

15   characteristics such as $\Delta R/R$ which will be set forth in greater detail hereinafter.

Free layer **110**, spacer **115**, pinned layer **120**, the AFM layer **125**, and the underlayer

126 are all formed in the central region **102**. Hard bias layers **130** and **135** formed in the end

regions **104** and **106**, respectively, provide longitudinal bias for the free layer **110**. Leads **140**

and **145** formed over hard bias layers **130** and **135**, respectively, provide electrical

20   connections for the flow of the sensing current I_s from a current source **160** to the MR sensor

100. Sensor **170** is connected to leads **140** and **145** senses the change in the resistance due to

changes induced in the free layer **110** by the external magnetic field (e.g., field generated by a

data bit stored on a disk). IBM's U.S. Pat. No. 5,206,590 granted to Dieny et al. and

incorporated herein by reference, discloses an MR sensor operating on the basis of the spin

valve effect.

Another type of spin valve sensor is an anti-parallel (AP)-pinned spin valve sensor.

FIG. 2A shows an exemplary AP-Pinned spin valve sensor 200 (not drawn to scale). Spin

5   valve sensor 200 has end regions 202 and 204 separated from each other by a central region

206. AP-pinned spin valve sensor 200 comprises a Ni-Fe free layer 225 separated from a

laminated AP-pinned layer 210 by a copper spacer layer 220. The magnetization of the

laminated AP-pinned layer 210 is fixed by an AFM layer 208, or pinning layer, which is made

of NiO. Again, beneath the AFM layer 208 is an underlayer 209. The laminated AP-pinned

10   layer 210 includes a first ferromagnetic layer 212 (PF1) of cobalt and a second ferromagnetic

layer 216 (PF2) of cobalt separated from each other by a ruthenium (Ru) anti-parallel

coupling layer 214. The AMF layer 208, AP-pinned layer 210, copper spacer 220, free layer

225 and a cap layer 230 are all formed sequentially in the central region 206. Hard bias layers

235 and 240, formed in end regions 202 and 204, provide longitudinal biasing for the free

15   layer 225. Electrical leads 245 and 250 are also formed in end regions 202 and 204,

respectively, to provide electrical current from a current source (not shown) to the spin valve

sensor 200.

Various parameters of a spin valve sensor may be used to evaluate the performance

thereof. A couple of examples of such parameters are the structure sheet resistance (R) and

20   GMR ratio ($\Delta R/R$). The GMR ratio ($\Delta R/R$) is defined as $(R_{AP} - R_P)/R_P$, where R_{AP} is the anti-

parallel resistance and R_P is the parallel resistance.

Numerous theoretical studies have attempted to explain the behavior of spin valve

effects. However, there does not currently exist an explanation of the main factors controlling

the magnitude of the sensor response, as characterized by $\Delta R/R$, as it relates to the required

properties of the conductive spacers and ferromagnetic (FM) layers constituting such device. Experimental efforts have been largely based on trial and error, by investigating various combinations of FM layers and conductive spacer layers. None of the previous work has yielded quantitative guidelines for the maximization of $\Delta R/R$ for spin valve sensors by

5   providing selection criteria for the layer compositions of the FM material and the conductive spacer.

What is known is that the GMR effect depends on the angle between the magnetizations of the free and pinned layers. More specifically, the GMR effect is proportional to the cosine of the angle ß between the magnetization vector of the pinned layer

10   (M_P) and the magnetization vector of the free layer (M_F) (Note FIGs. **2B** and **2C**). In a spin valve sensor, the electron scattering and therefore the resistance is maximum when the magnetizations of the pinned and free layers are antiparallel, i.e., majority of the electrons are scattered as they try to cross the boundary between the MR layers. On the other hand, electron scattering and therefore the resistance is minimum when the magnetizations of the pinned and

15   free layers are parallel; i.e., majority of electrons are not scattered as they try to cross the boundary between the MR layers.

In other words, there is a net change in resistance of a spin valve sensor between parallel and antiparallel magnetization orientations of the pinned and free layers. The GMR effect, i.e., the net change in resistance, exhibited by a typical prior art spin valve sensor is

20   about 6% to 8%.

In prior art spin valve sensors, the AFM layer (**125, 208** of FIGs. **1** and **2**, respectively) has the antiferromagnetism thereof strongly affected by the underlayer (**126, 209** of FIGs. **1** and **2**, respectively). As a result, the magnetizations of the pinned and free layers are varied with the material of the underlayer.

In particular, the AFM layer fails to operate perfectly due to the underlayer. For

example, the use of conventional underlayer materials such as zirconium (Zr) is deficient in

resistance due to corrosion. This phenomenon in turn causes the magnetizations of the

pinned and free layers to be weak since the pinned layer is not fully fixed. As a result, it has

5   been difficult to obtain optimum operation because the direction of magnetization of the

pinned layer varies relative to the signal magnetic field.

There is therefore a need for an improved underlayer in a spin valve sensor that alters

R and $\Delta R/R$ to improve overall performance of a spin valve sensor.

DISCLOSURE OF THE INVENTION

It is an object of the present invention to disclose an improved spin valve sensor that alters R and ΔR/R for overall improved performance.

It is another object of the present invention to disclose an improved spin valve sensor

5   with a layer of NiFe and/or CoFe over an underlayer thereof.

It is still another object of the present invention to disclose a method of fabricating an improved spin valve sensor with a layer of NiFe and/or CoFe over an underlayer thereof.

These and other objects and advantages are attained in accordance with the principles of the present invention by disclosing a spin valve sensor system and a method for fabricating

10   the same. Such spin valve sensor includes a pinned layer having a pinned layer magnetization. Also included is a free layer disposed adjacent the pinned layer. The free layer has a free layer magnetization perpendicular to the pinned layer magnetization in the absence of an external field. A pinning layer is disposed adjacent the pinned layer for fixing the pinned layer magnetization. Further included is an underlayer disposed adjacent the

15   pinning layer. Such underlayer comprises NiFeX. Disposed adjacent the underlayer and the pinning layer is an upper layer. The upper layer comprises a material selected from the group consisting of NiFe and CoFe for increasing a GMR ratio associated with the spin valve sensor.

In one embodiment of the present invention, the upper layer may be deposited with a

20   thickness of at least 4 A. Optionally, the upper layer may have a thickness of no more than 20 A. Still yet, the upper layer may be doped. To deposit the upper layer, physical vapor deposition (PVD) sputtering may be utilized.

In another embodiment of the present invention, the underlayer may include NiFeCr. As an option, the underlayer may include 40 +/- 5 Atomic % Cr. It should be noted that the

spin valve sensor may take any form such as a top spin valve, a bottom spin valve, a dual spin valve, and/or an anti-parallel (AP)-pinned spin valve sensor.

In another aspect of the present invention, a method may be provided for fabricating the spin valve sensor. During such method for a bottom spin valve, an underlayer of NiFeX is

5   deposited after which an upper layer is sputtered adjacent the underlayer. As set forth hereinabove, the upper layer comprises a material selected from the group consisting of NiFe and CoFe. Thereafter, a pinning layer (in addition to free and pinned layers) is disposed adjacent the upper layer.

BRIEF DESCRIPTION OF THE DRAWINGS

10   For a fuller understanding of the nature and advantages of the present invention, as well as the preferred mode of use, reference should be made to the following detailed description read in conjunction with the accompanying drawings.

FIG. 1 is a schematic diagram of the cross-section of a prior art spin valve sensor;

FIG. 2A shows an AP-Pinned spin valve sensor in accordance with the prior art;

15   FIGS. 2B and 2C illustrate a perspective of the free and pinned layers, and a diagram of the magnetization vectors, respectively, of a prior art spin valve sensor;

FIG. 3 is a perspective drawing of a magnetic recording disk drive system;

FIG. 4 is a schematic diagram of the cross-section of the preferred spin valve sensor of the present invention;

20   FIG. 5A is a schematic diagram of the cross-section of a thin film structure in accordance with one embodiment of the present invention;

FIGS. 5B-1 and 2 show two exemplary embodiments of the use of an upper layer above the underlayer for improving the operational characteristics of the spin valve sensor; and

Figure **6** shows the dependence of the spin valve GMR ratio on a thickness of a NiFe

upper layer inserted on top of a NiFeCr underlayer.

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BEST MODE FOR CARRYING OUT THE INVENTION

The following description is the best embodiment presently contemplated for carrying

out the present invention. This description is made for the purpose of illustrating the general

principles of the present invention and is not meant to limit the inventive concepts claimed

5   herein.

Referring now to FIG. 3, there is shown a disk drive 300 embodying the present

invention. As shown in FIG. 3, at least one rotatable magnetic disk 312 is supported on a

spindle 314 and rotated by a disk drive motor 318. The magnetic recording media on each

disk is in the form of an annular pattern of concentric data tracks (not shown) on disk 312.

10   At least one slider 313 is positioned on the disk 312, each slider 313 supporting one or

more magnetic read/write heads 321 where the head 321 incorporates the MR sensor of the

present invention. As the disks rotate, slider 313 is moved radially in and out over disk

surface 322 so that heads 321 may access different portions of the disk where desired data are

recorded. Each slider 313 is attached to an actuator arm 319 by way of a suspension 315. The

15   suspension 315 provides a slight spring force which biases slider 313 against the disk surface

322. Each actuator arm 319 is attached to an actuator 327. The actuator 327 as shown in FIG.

3 may be a voice coil motor (VCM). The VCM comprises a coil movable within a fixed

magnetic field, the direction and speed of the coil movements being controlled by the motor

current signals supplied by controller 329.

20   During operation of the disk storage system, the rotation of disk 312 generates an air

bearing between slider 313 and disk surface 322 which exerts an upward force or lift on the

slider. The air bearing thus counter-balances the slight spring force of suspension 315 and

supports slider 313 off and slightly above the disk surface by a small, substantially constant

spacing during normal operation.

The various components of the disk storage system are controlled in operation by control signals generated by control unit **329**, such as access control signals and internal clock signals. Typically, control unit **329** comprises logic control circuits, storage and a microprocessor. The control unit **329** generates control signals to control various system

5   operations such as drive motor control signals on line **323** and head position and seek control signals on line **328**. The control signals on line **328** provide the desired current profiles to optimally move and position slider **313** to the desired data track on disk **312**. Read and write signals are communicated to and from read/write heads **321** by way of recording channel **325**.

The above description of a magnetic disk storage system of the present invention, and

10   the accompanying illustration of FIG. **3** are for representation purposes only. It should be apparent that disk storage systems may contain a large number of disks and actuators, and each actuator may support a number of sliders.

Now referring to FIG. **4**, there is shown an air bearing surface (ABS) view of the spin valve sensor **400** (not drawn to scale) having the structure of Underlayer(including

15   NiFeCr)/NiFe /PtMn/CoFe/Ru/CoFe/Spacer/CoFe/NiFe/Ta and manufactured, using a sputter deposition process, according to the preferred embodiment of the present invention. Spin valve sensor **400** comprises end regions **404** and **406** separated by a central region **402**. A free layer (free ferromagnetic layer) **410**, comprising a NiFe layer and a thin CoFe layer, is separated from a pinned layer (pinned ferromagnetic layer) **420**, comprising a Ru layer and

20   two thin CoFe layers, by a non-magnetic, electrically-conducting spacer layer **415**. As an option, such electrically conducting spacer layer **415** may include CuO_x. The magnetization of the pinned layer **420** is fixed by an antiferromagnetic (AFM) layer **425**. An underlayer **429**, AFM layer **425**, pinned layer **420**, spacer layer **415**, free layer **410**, and a cap layer **408** are all formed in that order in the central region **402**.

The underlayer **429** or seed layer is deposited to modify the crystallographic texture or grain size of the subsequent layers. In accordance with a preferred embodiment of the present invention, such underlayer **429** has an upper layer **431** thereon which comprises a material selected from the group consisting of NiFe, CoFe, or a combination thereof. More

5   information regarding such improvement will be set forth in greater detail during reference to FIGS. **5-6**.

Referring still to FIG. **4**, the spin valve sensor **400** further comprises layers **430** and **435** formed in the end regions **404** and **406**, respectively, for providing a longitudinal bias field to the free layer **410** to ensure a single magnetic domain state in the free layer **410**.

10   Layers **430** and **435**, preferably made of hard magnetic material such as CoPtCr, are deposited and magnetically aligned at room temperature according to the well-known methods established in the prior art. Lead layers **440** and **445** are formed over hard bias layers **430** and **435** in the end regions **404** and **406**, respectively, by the methods known in the prior art.

Leads **440** and **445** provide electrical connections for the flow of the sensing current I_s

15   from a current source **460** to the spin valve sensor **400**. Sensor **470** is connected to leads **440** and **445** senses the change in the resistance due to changes induced in the free layer **410** by the external magnetic field (e.g., field generated by a data bit stored on a disk).

The above description of a spin valve sensor of the present invention, and the accompanying illustration of FIG. **4** are for representation purposes only. It should be

20   apparent that spin valve sensors may contain differing layers of varying materials for accomplishing similar results. Moreover, the spin valve sensor may include a top spin valve, a bottom spin valve, a dual spin valve, and/or any other type of spin valve per the desires of the user.

Referring now to FIG. **5A**, the sputter deposition process for fabrication of the central

25   region **402** of FIG. **4** of spin valve sensor **400** is shown (not to scale) with deposition on a

substrate **500** of suitable underlayer **501** materials such as NiFeX. It should be noted that the Ni and Fe of the NiFeX may be combined with any desired material, X. For example, the underlayer **501** may include NiFeCr. As an option, the underlayer **501** may include 40 +/- 5 Atomic % Cr.

5   An upper layer **508** is deposited above the underlayer **501** for improving the operational characteristics of the spin valve sensor. In one embodiment, the upper layer **508** may include NiFe, CoFe, or any combination thereof with any desired elements. For example, the upper layer **508** may be doped.

While such upper layer **508** may be deposited in any desired manner, physical vapor

10   deposition (PVD) sputtering may be utilized in one embodiment. PVD sputtering is commonly used for depositing metal films and the like onto substrate surfaces. A planar target is typically positioned within a chamber, in spaced apart and symmetrical counterfacing relation with the substrate. The target is made of the material that is to be sputter deposited onto the substrate surface. Emission-inducing energy is applied to the active face of the target

15   in the form, for example, of a plasma containing accelerated argon ions. In response to such bombardment, the active face of the target emits small particles composed of the target material. The emitted particles follow a generally linear trajectory from their point of emission on the target surface to a collision point on the counterfacing surface of the substrate. Physical adhesion mechanisms cause the target particles to bond to the surface of

20   the substrate.

In one embodiment of the present invention, the upper layer **508** may be deposited with a thickness of at least 4 A. Optionally, the upper layer **508** may have a thickness of no more than 10 A after which benefits are abated. Further, the upper layer **508** may have a thickness of no more than 20A after which benefits are seriously abated.

Thereafter, an antiferromagnetic (AFM) pinning layer **507** is deposited. The preferred

composition of the AFM layer is a PtMn composition **510**. It should be noted that, in the

present description, the notation "PtMn" (or any other combination of materials) refers to any

desirable amount of either materials, i.e. Pt - Mn. A pinned layer **511** is subsequently

5   deposited in direct contact and overlaying the pinning layer **507**. The pinned layer **511**

includes a CoFe layer **512** followed by a Ru layer **514** and another CoFe layer **516**.

Following the pinned layer **511**, a spacer layer **518** is deposited such as CuO_x.

The above description of a spin valve sensor structure of the present invention, and

the accompanying illustration of FIG. **5A** are for representation purposes only. Such spin

10   valve sensor structure is that which was used to produce the analysis data set forth

hereinbelow. Such data shows improvements associated with applying the principles of the

upper layer **508** over the underlayer **501** of the present invention. It should be noted,

however, that other spin valve sensor structures including differing layers of varying materials

may be employed while still achieving improvements unique to the additional layer covering

15   the underlayer **501**.

FIGS. **5B-1** and **2** show two exemplary embodiments of the use of the upper layer **508**

above the underlayer **501** (not drawn to scale) for improving the operational characteristics of

the spin valve sensor. It should be noted that such exemplary embodiments are for illustrative

purposes only, and that any desired combination of NiFe and CoFe may be utilized with any

20   NiFeX structure. FIG. **5B-1** illustrates a first embodiment where NiFeCr **530** is covered with

NiFe **532**. FIG. **5B-2** illustrates a second embodiment where NiFeCr **540** is covered with

CoFe **542**.

It has been shown that an application of 4 A or more NiFe or CoFe upper layer **508** on

top of an underlayer **501** including NiFeCr greatly improves the GMR ratio ($\Delta R/R$). GMR

ratios have been improved from 9.0% to 12.8% in the device-quality bottom PtMn AP-pinned

spin valve structures of next generation recording heads. An example of such next generation

recording heads is the IBM GMR 5.5 series record head. As is well known in the art, a high

GMR ratio is essential in improving the performance of the spin valve sensors.

5   Figure 6 shows the dependence of the spin valve GMR ratio on the thickness of NiFe

upper layer 508 inserted on top of the underlayer 501. An increase in $\Delta R/R$ from 7.0% to

12.8 % is observed with just a few Angstroms thick NiFe upper layer 508. The same

Characteristics are obtained with a CoFe upper layer 508. It is also expected that the use of

other upper layers 508 with similar microstructure (e.g., appropriately doped NiFe or CoFe)

10   would lead to the same effect.

In addition to inducing the increase in $\Delta R/R$, insertion of the upper layer 508 lowers

the structure sheet resistance R, and increases the pinning field. It may be found that the

addition of the upper layer 508 may have no effect on the interlayer coupling field H_f.

It should be noted that a 10 A thick upper layer 508 inside the structure set forth

15   hereinabove does not have a measurable magnetic moment associated therewith. Application

of an upper layer 508 thicker than 10 A works as well, but it does not lead to further $\Delta R/R$

improvement. In fact, it eventually leads to increased current shunting and buildup of

magnetic moment in the underlayer 501. This can be undesirable in some applications. Such

detrimental effects could likely be prevented by using a non-magnetic, high-resistivity (e.g.,

20   appropriately doped NiFe or CoFe) upper layer 508.

As will be apparent to one skilled in the art, the fabrication methods of the preferred

embodiment and the alternative embodiments described herein may be used to fabricate spin

valve sensors having any other layered structure, i.e. underlayer/pinned layer/spacer/free

layer. Further, it should be noted that the various principles of the present invention may be applicable in a very broad range of spin valve sensor devices.

While various embodiments have been described above, it should be understood that they have been presented by way of example only, and not limitation. Thus, the breadth and scope of a preferred embodiment should not be limited by any of the above-described exemplary embodiments, but should be defined only in accordance with the following claims and their equivalents.